PDETool

Version 1.0.6

User Manual

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http://pdel.iust.ac.ir/projects/pdetool.html

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Introduction

PDETool is a multi-formalism modeling and simulation framework for discrete-event models based on a unified abstract description named SDES [1]. It uses a simulation engine for simulation of discrete-event simulation of stochastic models called ***SimGine***. PDETool can be easily extended to support variety of stochastic formalisms. It currently supports SANs, CSANs, GSPNs and SRNs (which will be explained next).

The Software Architecture

The software architecture of PDETool, shown in Figure 1, is separated to two layers: a front-end layer and a back-end layer as follows:

- **Front-End Layer (PDETool interface)**: This layer provides some graphical user interfaces and a model translator. The user interfaces includes editors (model editor, reward variables editor, global variable editor), SimGine interface, simulation and animation GUI described in the previous subsection. Each formalism supported by the tool has its own editor, translator and an optional graphical animator which are responsible for communicating with the underlying layer. This layer can be viewed as an interface between users and the back-end layer.
- **Back-End Layer (SimGine engine)**: PDETool uses SimGine simulation engine as the underlying layer. This back-end layer is responsible for simulation of the model and evaluating reward variables and also provides model animation facility. As we mentioned before, for simulating a model based on particular stochastic discrete-event formalism, a model translator prepares the input model of SimGine mapped from the original model where these two models should be behaviorally equal. As depicted in Figure 1, the internal architecture of SimGine includes parser, code generator, utility library, simulator, animator and SDES simulation manager.

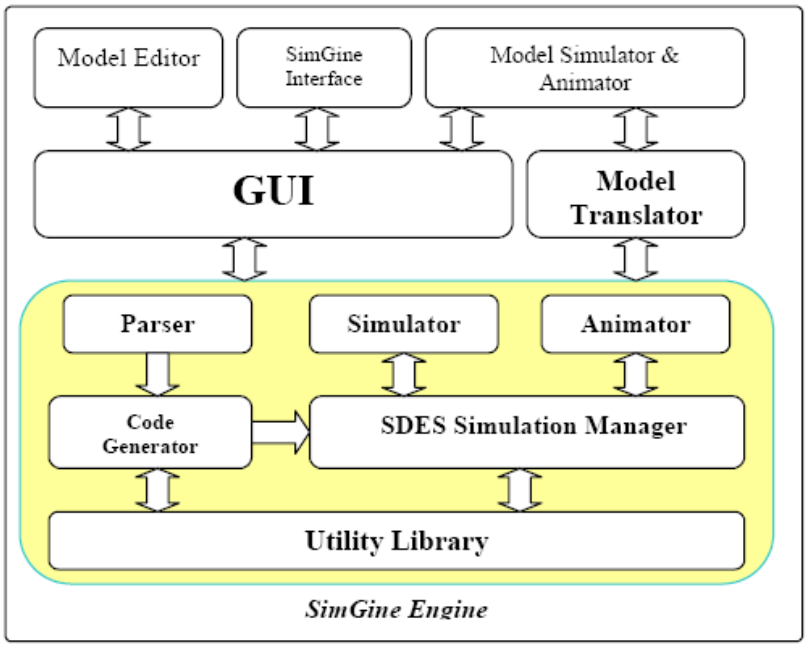


Figure 1 The software architecture of PDETool and SimGine

PDETool background

As mentioned before, PDETool uses SimGine for discrete-event simulation of stochastic models. SimGine is a simulation engine based on SDES unified description and has its own model structure and file format. For simulating a model based on a particular formalism in PDETool, the model must be translated into the XML-based input language of SimGine. For more information about SDES description, see [1]. More information about SimGine and its manual are also available in SimGine homepage [7].

Installation

PDETool runs under Microsoft Windows XP/2000/Vista and needs .Net Framework (version 2 or higher) to be installed on the system. If you do not have it installed on your system, you must first install .Net framework.
NOTE: PDETool is not tested on Windows 95, 98, Millennium and NT. But we guess it will work in these versions of Microsoft windows if .Net framework is installed. The last version of .Net framework (currently version 3.5) can be freely downloaded from http://msdn.microsoft.com/en-us/netframework/default.aspx.

Installing SimGine and PDETool

To install PDETool, download and run PDETool installation file from [8]. It installs both PDETool and SimGine and everything needed to construct a model and simulate it.

Modeling Background

PDETool supports multiple formalisms, including generalized stochastic Petri nets (GSPNs), stochastic reward nets (SRNs), stochastic activity networks (SANs) and coloured stochastic activity networks (CSANs). In this section, we review some modeling background about these models.

Petri Nets (PNs)

Petri nets originally were introduced by C.A. Petri in 1962 [3]. A Petri net (PN or sometimes Place-Transition net) is a bipartite directed graph whose nodes are divided into two disjoint sets called *places* and *transitions*. Directed arcs in the graph connect places to transitions (called input arcs) and transitions to places (called output arcs). A cardinality number may be associated with these arcs. A marked Petri net is obtained by associating tokens with places. A marking of a PN is the distribution of tokens in the places of the PN. There are several definitions for Petri nets and even more for stochastic Petri nets. Petri net formally can be defined by a 4-tuple (*P*, *T*, *A*, *M*) where:

- $P=\{p_1,p_2,\ldots,p_m\}$ is a finite non-empty set of places,
- $T=\{t_1,t_2,\ldots,t_n\}$ is a finite non-empty set of transitions where $P \bigcap T = \phi$,
- $A = (P \times T) \bigcup (T \times P)$ is the set of (input and output) arcs,
- $M:P \rightarrow \{0,1,2,\ldots\}$ is the marking of net which denotes the number of tokens in each place *P*. Initial marking is denotes as M_0.

In a graphical representation of a PN, places are represented by circles, transitions are represented by bars and the tokens are represented by dots or integers in the places. Input places of a transition are the set of places which are connected to the transition through input arcs. Similarly, output places of a transition are those places to which output arcs are drawn from the transition. A transition is considered enabled in the current marking if the number of tokens in each input place is at least equal to the cardinality of the input arc from that place. The firing of a transition is an *atomic action* in which one or more tokens are removed from each input place of the transition and one or more tokens are added to each output place of the transition, possibly resulting in a new marking of the PN. Upon firing the transition, the number of tokens deposited in each of its output-places is equal to the cardinality of the output-arc.

Each distinct marking of the PN constitutes a separate state of the PN. A marking is reachable from another marking if there is a sequence of transition firings starting from the original marking which results in the new marking. The reachability set (graph) of a PN is the set (directed graph) of markings that are reachable from the other markings (connected by the arcs labeled by the transitions whose firing causes the corresponding change of marking). In any marking of the PN, multiple transitions may be simultaneously enabled.

Generalized Stochastic Petri Nets (GSPNs)

The stochastic PNs (SPNs) [4] are obtained by associating with each transition in a PN an exponentially distributed firing time. An SPN model can be formally defined by a five tupple *(P, T, A, M, R)* where *P*, *T*, *A*, and *M* are as in simple Petri nets, and *R* is the set of firing rates (possibly marking-dependent) associated with the PN transitions where

$$R = \{r_1, r_2, \ldots, r_m\}$$

The underlying reachability graph of a SPN model is isomorphic to a continuous time Markov chain (CTMC).

Generalized stochastic Petri nets (GSPNs) [5] try to extend SPNs further by introducing *immediate transitions* which fire in zero time once they are enabled in addition to *timed transitions* that fire after a random, exponentially distributed enabling time (like in SPNs). Usually, timed transitions are represented by hollow rectangles while immediate transitions are represented by thin bars.

The markings of a GSPN are classified into two types. A marking is vanishing if any immediate transition is enabled in the marking. A marking is tangible if only timed transitions or no transitions are enabled in the marking. If several conflicting immediate transitions are enabled in a marking, a firing probability must be defined. The (usually marking dependent) *firing probability* is specified for only timed transitions and does not need to be specified for timed transitions.

Another type of arc exists in GSPN called *inhibitor arc*. An inhibitor arc connects a place *p* to a transition and imposes an additional constraint on the enabling of that transition. The transition is now enabled iff the enabling rule of ordinary Petri nets concerning the usual arcs between places and that transition is satisfied and if the place is not marked (is empty).

A GSPN model describes an underlying stochastic process, captured by the extended reachability graph" (ERG) as a reachability graph with additional stochastic information on the arcs which can be reduced to a CTMC in the state space analysis step.

Stochastic Reward Nets (SRNs)

Stochastic reward nets (SRNs) [6] are based on GSPN but extend it further. In SRNs, every tangible marking can be associated with a reward rate. It can be shown that an SRN can be mapped into a Markov reward model. Thus a variety of performance measures can be specified and calculated using a very convenient formalism. SRN also allows several other features that make specification convenient.

Each transition may have an enabling function (also called a *guard*), so that a transition is enabled only if its marking dependent enabling function is true. This feature provides a powerful means to simplify the graphical representation and to make SRNs easier to be understood.

Marking dependent arc multiplicities are allowed. This feature can be applied when the number of tokens to be transferred depends on the current marking. *Marking dependent firing rates* are allowed. This feature allows the firing rate of the transitions to be specified as a function of the number of tokens in any place of the Petri net,

Transitions can be assigned different *priorities* and a transition is enabled only if no other transition with a higher priority is enabled,

Besides the traditional output measures obtained from a GSPN, such as throughput of a transition and the mean number of tokens in a place, more complex reward function can be defined.

Stochastic Activity Networks (SANs)

Stochastic activity networks (SANs) [10], introduced in 1984, are a stochastic extension of Petri nets [3]. SANs are more powerful and flexible than most other stochastic extensions of Petri nets that use graphical primitives and provide a high-level modeling formalism with which detailed performance, dependability, and performability models can be specified relatively easily. PDETool uses a new definition of SANs which is introduced in [12].

Each SAN model is composed of the following elements (primitives):

- **Place**:

  Like any extension of Petri nets, places which represent the state of the modeled system, are represented graphically as circles. Each place contains a certain number of tokens (an Integer value), which represents the marking of the place. The set of all places' marking defines the marking of the model. All tokens in a SAN place are homogeneous, in that only the number of tokens in a place is known; there is no identification of different kinds of tokens within a place. Graphically, each place is represented as a circle.

- **Timed activity**:

  Timed activities represent activities of the modeled system whose durations impact the system's ability to perform. A timed activity has m inputs and n outputs, where $m+n>0$. Each input can be a place or an input gate and each output can also be a place or an output gate. To each timed activity is associated an *enabling rate function* (i.e. a computable partial function, which is the activity execution speed), and an *n-ary* computable predicate called the *reactivation predicate*. Timed activities are represented graphically as thick vertical lines.

  Enabling rate functions can be generally distributed random variables. Each distribution can depend on the marking of the network. For example, one distribution parameter could be a constant multiplied by the marking of a certain place.

  Reactivation predicate function gives marking dependent conditions under which an activity is reactivated. Reactivation of an activated activity means that the activity is aborted and that a new activity time is immediately obtained from the activity time distribution.

- **Instantaneous activity**:

  Instantaneous activities represent system activities, which, relative to the performance variable in question, are completed in a negligible amount of time. These activities are represented graphically as thin vertical lines. An instantaneous activity has m inputs and n outputs, where $m+n>0$.

- **Input gate**:

  Gates are introduced to permit greater flexibility in defining enabling and completion rules. An input gate has a finite set of inputs and one output. To

each such input gate is associated an *n-ary* computable predicate called the *enabling predicate*, and a computable partial function called the *input function*. An input gate is represented graphically as a triangle.
The enabling predicate is a Boolean function that controls whether the connected activity is enabled or not and can be any function of the markings of the input places. The input gate function defines the marking changes that occur when the activity completes.
If a place is directly connected to an activity with an arc, it is equivalent to an input gate with a predicate that enables the activity when ever the place has more than zero tokens along with a function that decrements the marking of the place by one when ever the activity fires. An input gate is represented as follows:

- **Output gate**:
  An output gate which is represented by triangle has a finite set of outputs and one input. To each such output gate is associated a computable function called the *output function* which defines the marking changes that occur when the activity completes. Like in input gates, there is also a default scenario for output gates, i.e. if an activity is directly connected to a place, it is equivalent to an activation in which an output gate has a function that increments the marking of the place whenever the activity is fired. An output gate represented as bellows:

Structurally, a SAN model is an interconnection of a finite number of primitives, subject to the following connection rules:

- Each input of an input gate is connected to a unique place and the output of an input gate is connected to a single activity.
- Different input gates of an activity are connected to different places.
- Each output of an output gate is connected to a unique place and the input of an output gate is connected to a single activity.
- Different output gates of an activity are connected to different places.
- Each place and activity is connected to some input or output gates.

Note: Be aware that the order in which state updates occur in PDETool may differ from some other tools. Input gates execute before arcs directly connect places and activities and they execute before output gates in PDETool. Also, if there are multiple instances of the same item, for instance multiple input gates, and the order of application of the gates is not specified. Models must be constructed so that the gate functions are execution order independent anytime there are multiple instances of the same type of gates connected to an activity.

Coloured Stochastic Activity Networks (CSANs)

A CSAN model 13] is composed of the five primitives of a new definition of SANs, including place, input gate, output gate, timed activity and instantaneous activity, plus a new type of places called *coloured place*. A coloured place holds a list of tokens of a user-defined token type. To differentiate the two kinds of places, we will refer to the ordinary places of SANs as simple place. The term place is used to refer to both kinds of places.

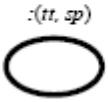
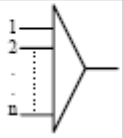
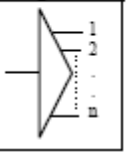
To each coloured place is associated a selection policy, which specifies the order of tokens for removal by the occurrences of linked activities. Different kinds of the selection policies are as follows:

- FIFO: In this case, tokens can be taken from the place in same order they have been appended.
- LIFO: In this case, tokens can be taken from the place in reverse order of their appendance.
- PRI: In this case, tokens have a priority that can be specified by a user-defined order function.
- NSP (no-selection-policy): In this case, the list of tokens is unordered. Therefore, a multi-set (or bag) can be used to hold tokens.

The type of the objects being held by a coloured place is defined by a token type. A token type can be defined similar to the declaration of data types, records or structures in high-level programming languages like C++, Java or C# (in PDETool) . Each token type has one or more data fields, which may be an ordinal type or a user-defined type.

Both of the number of tokens inside a coloured place (i.e. the size of the token list) and the values of its fields can be read in predicates and functions or can be read or manipulated by functions of input/output gates.

Table 1: Graphical notation of CSAN elements

Simple place	*coloured place*	*timed activity*	*inst. activity*	*input gate*	*output gate*
					

A graphical representation of the elements of CSANs is shown in Table 1. For the coloured place, *tt* is the name of a token type and *sp* is a selection policy for the place.

Overview of PDETool

This section looks into the graphical user interface (GUI) of PDETool and describes constructing, editing and simulating models by the tool.
After installation, you can run the tool using Start *Menu→PDELab→PDETool*. The main console of PDETool is shown in Figure 2.

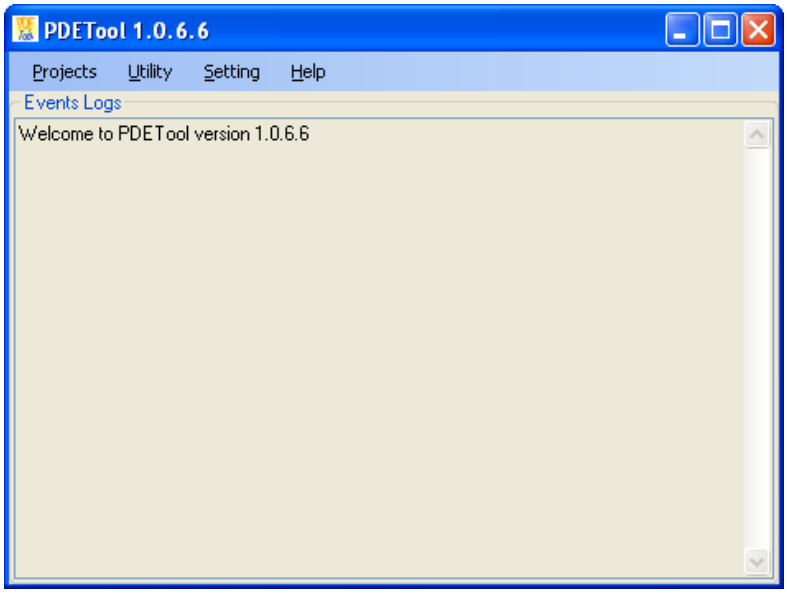


Figure 2 Main console of the PDETool

Before constructing a model, you have to create a new project or select one of existing ones using *Project Manager* (*Projects→New* or *Projects→Open*) which is shown in Figure 3.

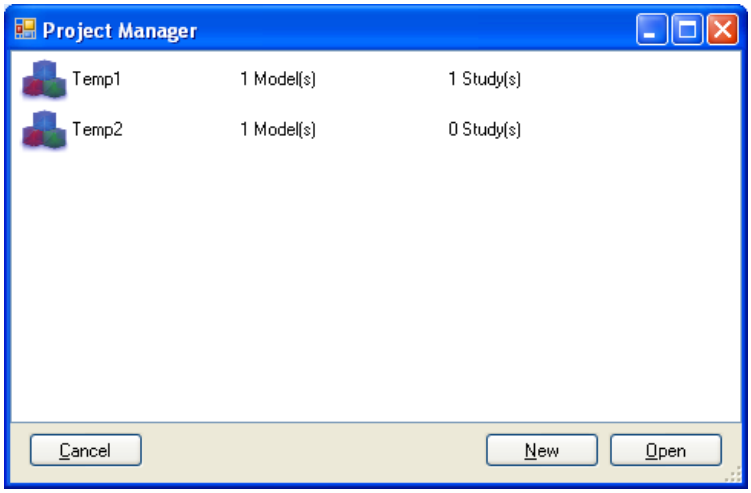


Figure 3 PDETool *Project Manager*

Constructing models

Opening a project in *Project Manager* or creating a new one, causes to open *Project Editor* depicted in Figure 4. In this form, you can create some models or some simulation studies to evaluate the existing models in the current project.

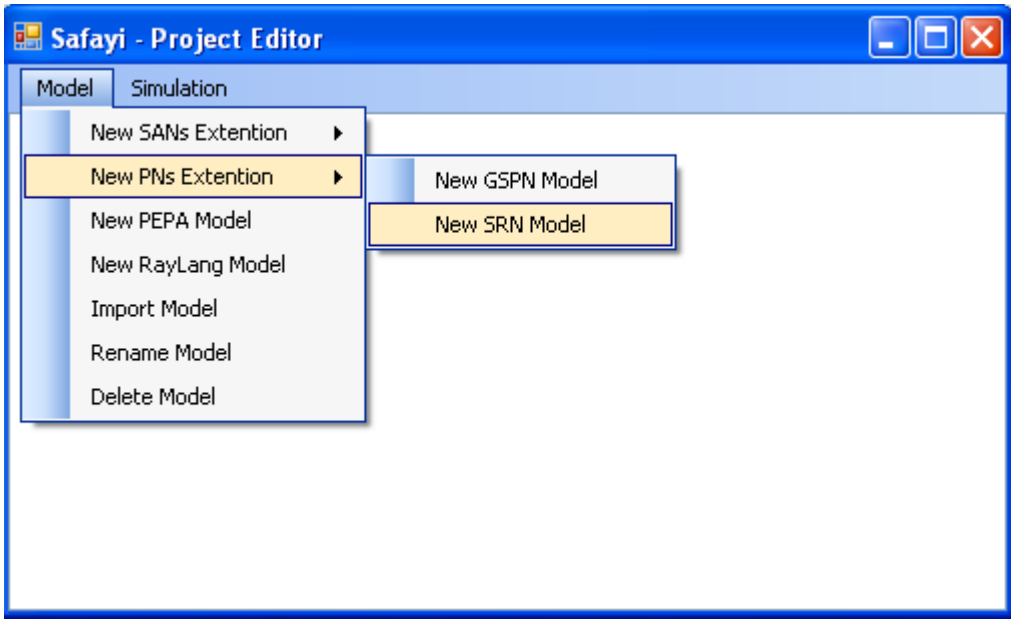


Figure 4 Project Editor

In *Project Editor*, you can create a new model in the current project or load and modify existing models as follows:

- To construct a new (SAN, CSAN, SRN and GSPN) model or rename/delete a selected existing one, use menu *Model* in Project Editor and select the proper submenu.

- To load an existing model, double click on it. It opens another form for editing and modifying models. The type of model editor depends on type of models, e.g. in case of SAN models, *SAN Model Editor* will be opened.
- You can also import a model from another project into the current project (*Model→Import Model*).

Adding/editing SAN elements

For constructing and modifying a SAN model, you must use *SAN Model Editor*. As shown in Figure 6, SAN Model Editor includes 6 parts: a textual menu (1), a graphical menu (2), model grid (3), reward variable list (4), global variable list (5) and properties editor (6).

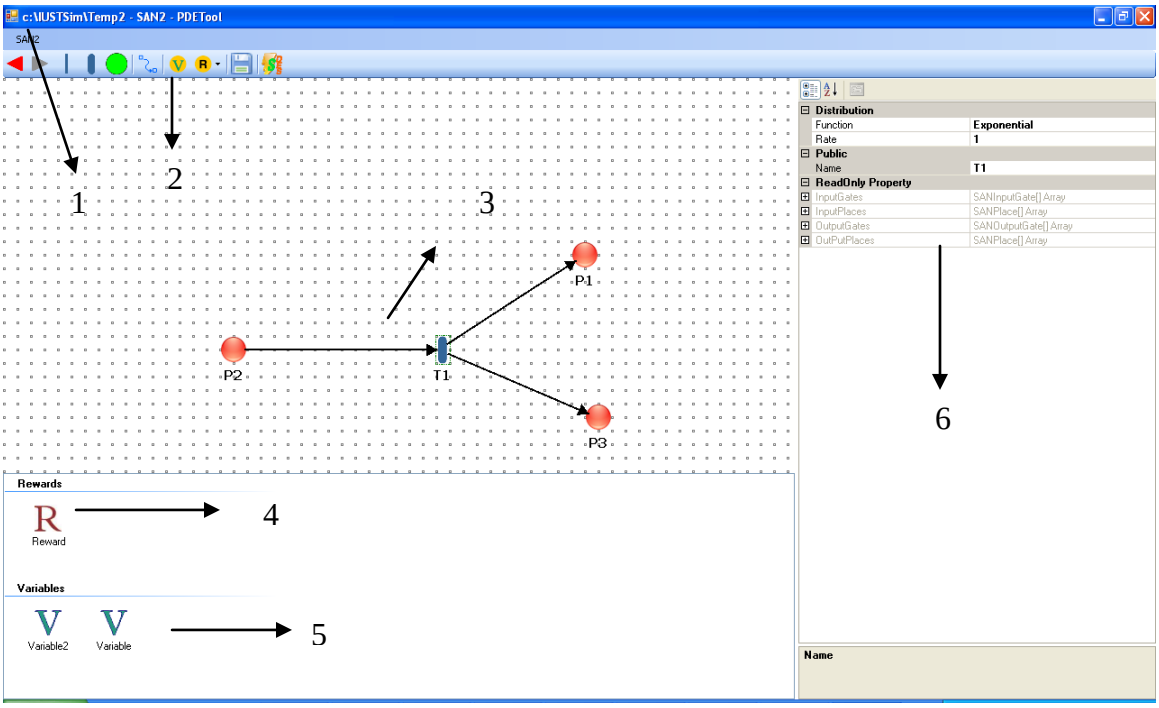


Figure 5 SAN Model Editor

To add a new SAN primitive, you must use graphical menu shown in Figure 6. To add a new ***Place, Timed Activity, Instantaneous Activity, Input Gate* or *Output Gate***, drag the proper icon (Figure 6) to the model grid and drop whenever you want (location of the new place). To connect two SAN elements (places to gates, gates to activities, places to activities and opposite sides of them) by an ***Arc***, push the icon Arc (Figure 6-6). Now, (left) click the first element of the connection and while holding the button, move the mouse to the destination of the connection and release the mouse button (Something like drag and drop). In Figure 6, Icons include: (1) input gate, (2) output gate, (3) instantaneous activity, (4) timed activity, (5) place, (6) arc, (7) global variable, (8) reward, (9) save and (10) convert to SDES.

Figure 6 *SAN Model Editor* graphical menu.

Graphical and textual editors also can be used to:

- Add a global variable and reward variable (Figure 6-7 and 8): This will be explained in detail in the following subsections.
- Save the current model: To save the current SAN model, push icon *Save* (Figure 6-9). It can be done using the textual menu too.
- Convert to SimGine input: To convert the current SAN model into the input language of SimGine, push icon *Convert to SDES* in the graphical menu (Figure 6-10).
- Export models as an image: SAN Model Editor can export current SAN model into an image with type JPEG. To do so, use textual menu (*Model→Export as Image*) and specify destination location of the output image file.

Modifying properties of SAN elements

Note that name (identifier) of each element (as an object), primitive or variable must be unique in the model. Properties of each element in a SAN model can be accessed and modified via *Property Editor* (right hand of the *Model Editor* as presented in Figure 6-6). Like traditional programming languages, names (identifiers) can be defined by a string which satisfies some constraints. Here, the lexical rules (constrains) that names must be satisfied is as existed in .NET languages.
In the subsequent paragraphs, we will describe attributes of each element type:

1. **Place**:
   - Name: A unique name that identifies the place. Marking of a place *p* (in functions defined in a gate) can be accessed/modified by property *Mark*. For example, one can write *p.Mark=2*.
   - Initial Marking: The initial marking *m* of each place is an integer value equal with or greater than zero ($m \geq 0$). Initial marking must be as an (explicit) integer number or value of a global variable within type *int*.
   - Position: Position of a place is a set *(x,y)* where *x* and *y* is horizontal and vertical position of the place in the model editor' grid. This property (as the common property of all graphical elements of SAN) is not shown in *Property Editor* but you can change the position of each element by dragging the element, move it and drop it somewhere else.

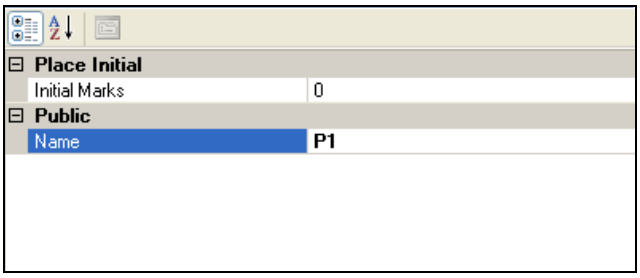


Figure 7 Place properties

2. **Timed Activity**:
   - Name: A unique name that identifies the timed activity.
   - Distribution: It includes both a distribution function and its parameters. For example, if execution of an activity is distributed exponentially, the mean of distribution must be specified. Each distribution function has one or more parameters which must be specified in *Distribution Editor* (Figure 9).
   - Reactivation predicate: A Boolean function (an expression or a sequence of statements written in C# that return a Boolean value) which reactivates the activity in a state that the activity is enabled and reactivation predicate is true. Reactivation means that a new delay will be sampled from the distribution function, and the activity will be scheduled to fire after "*delay*" units of time from the current simulation time.

Some read only properties are also shown in both instantaneous and timed activity including input gates, output gates, input places and output places. These properties show that which elements are connected to the activity (e.g. places that are connected as the input places of this activity). When you change the model or modify it, these properties change automatically.

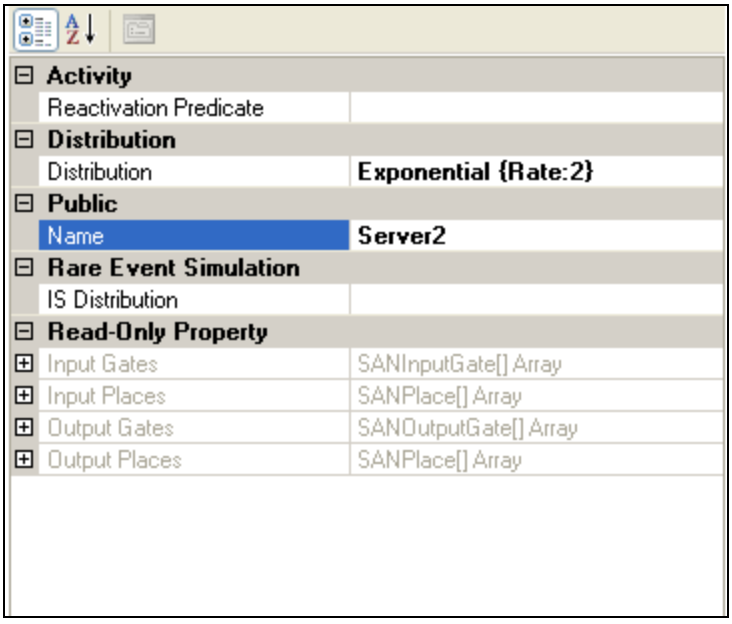


Figure 8 Timed Activity properties

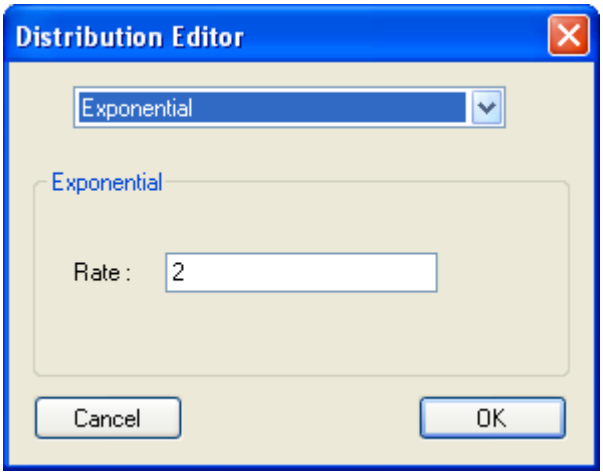


Figure 9 Distribution Editor

3. **Instantaneous Activity**:
   - Name: A unique name that identifies the instantaneous activity.
   - Probability (Weight): If two or more activities have the same completion time, these activities must compete probabilistically to determine which event completes first and the *Probability* is used to determine probability of firing each activity (these probability is normalized first).

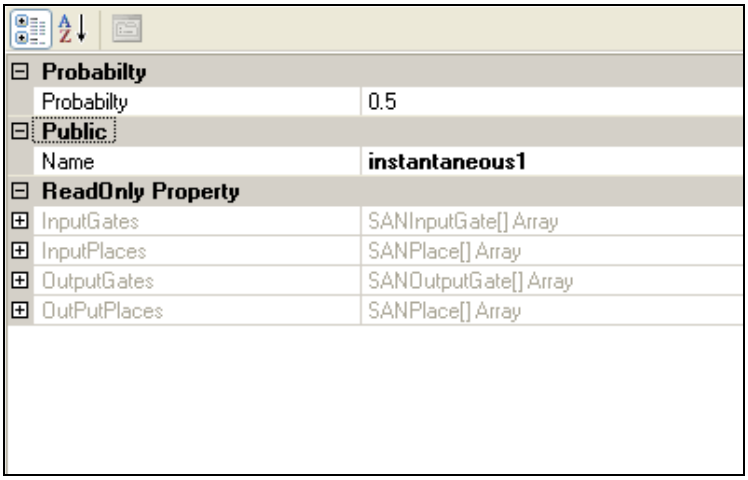


Figure 10 Instantaneous Activity properties

4. **Input Gate**:
   - Name: A unique name that identifies the input gate.
   - Enabling predicate: A Boolean function (an expression or a sequence of statements written in C# which return a Boolean vale).
   - Input function: A sequence of statements that their execution may change the state of model (marking of some places or value of some global variables) just before firing the activity which is connected to the gate.

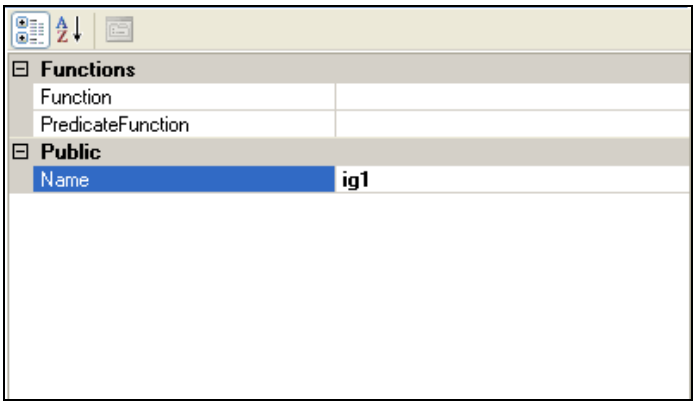


Figure 11 Input Gate properties

5. **Output Gate**:
   - Name: A unique name that identifies the output gate.
   - Output function: A sequence of statements that their execution may change the state of model (marking of some places or value of some global variables) just after firing the activity which is connected to the gate.

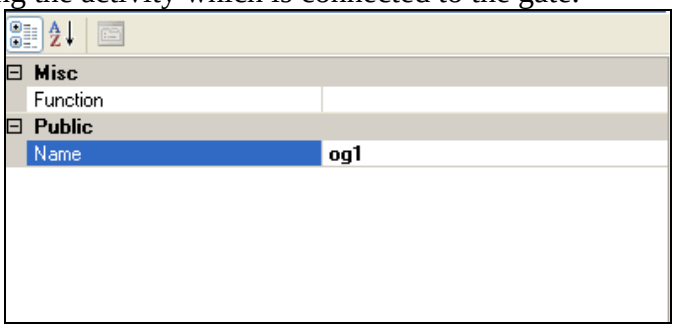


Figure 12 Output Gate properties

Adding/editing global variables

For adding global variables (which may change or remain constant during model execution), you have to use the global variable icon (Figure 6-7) in *SAN Model Editor*. For each global variable, a unique name must be chosen and type of the variable must be specified. Table 1 shows the available types for global variables.

Table 1: Available type for global variables

Type	Size (Byte)	Description
byte	1	signed byte
short	2	signed short
ushort	2	unsigned short
Int	4	signed integer
uint	4	unsigned integer
bool		a Boolean value
float	4	floating point number
double	8	double precision floating point number

After adding a global variable to the SAN model, you can change its name and type. To do so, select the variable in *Global Variable List* (Figure 6-4) and change properties of the variable in the *Properties Editor* (Figure 6-6). Figure 12 shows properties of variable *"Variable 1"* with type *"int"*.

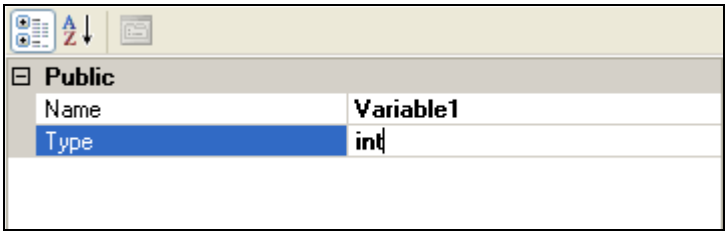


Figure 13 Global variable properties

Adding/editing CSAN elements

Primitives of CSANs are the same with SANs in addition to the following ones:

1. **Color**: A color is a data structure which can be used for colored tokens. To add a new color, use the graphical menu. A color is the list of fields with the following properties:
   - Name: A unique name that identifies the color.
   - An ordered list of fields. The type and name of each field must be specified. Type of each field must be a built-in type (Table 1) or a color that is defined before.
2. **Coloured Place**:
   - Name: A unique name that identifies the color.
   - Color: Color of the coloured place determines the type (color) of tokens can be in the place.
   - Policy: The policy determines how tokens are added or removed from the place and can be *FCFS* (for queue-like places), *LCLS* (for stack-like places) or *Priority*.
   - Priority Function: The body of function that is used when the policy of the place is *Priority*.
   - Initial marking: To specify the initial marking of a colored place, you have to specify the value of a colored token (values of all fields) and count of that token which should be added to the place (for example, see Figure 14 in which the initial marking of place has 6 coloured tokens that in 5 of them, field *a* is 1 and field *b* equals 4).

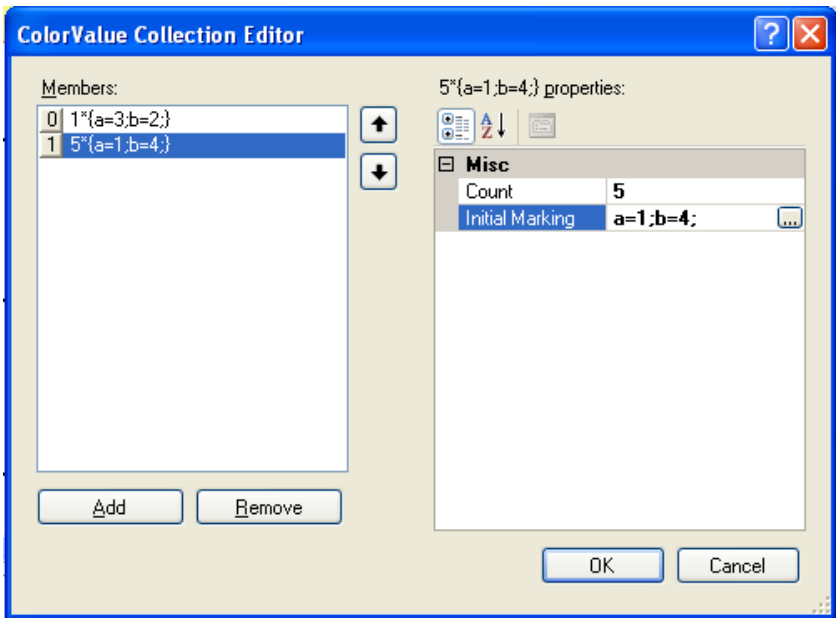


Figure 14 *Initial Marking Editor* for coloured places

Adding/editing SRN primitives

For constructing and modifying a SRN model, you have to use *SRN Model Editor*. As shown in Figure 13 and like in *SAN Model Editor*, *SRN Model Editor* includes 5 parts: a textual menu (1), a graphical menu (2), model grid (3), reward variable list (4), and properties editor (5).

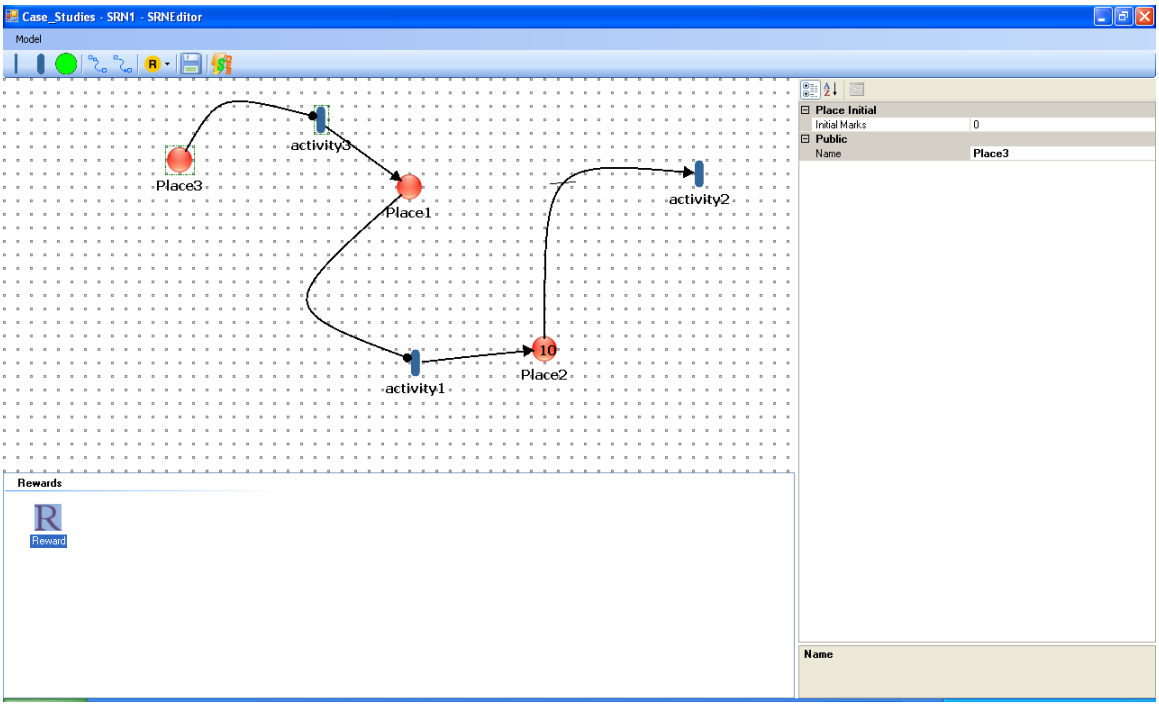


Figure 15 SRN Model Editor

Constructing SRN models is very similar to SANs and *SRN Model Editor* is somehow alike. In the following paragraphs, we only describe the differences.

1. **Place**:
   - Name.
   - Initial Marking.
2. **Timed transition:**
   - Name.
   - Rate. In SRNs, all timed transitions are exponentially distributed. Rate of firing can be a constant or a marking dependent number.
   - Guard. In addition of traditional enabling condition of each transition, there may exist another enabling condition named transition guard based on net marking. A guard is a Boolean expression and can use Boolean operators and marking of some places using property *Mark*, for instance *(p1.Mark<= 3 && p2.Mark==2) || (p3.Mark >= 5)*.
   - Priority. priorities is defined by assigning an integer priority level to each transition, and adding the constraint that a transition may be enabled only if no higher priority transition is enabled. A priority is an integer number greater than or equal to zero and greater number shows greater priority.

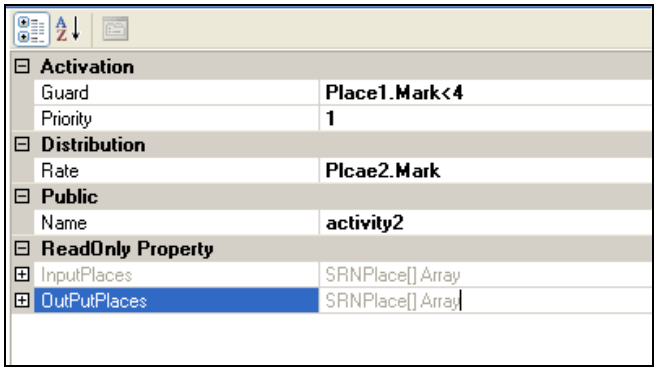


Figure 16 Timed transition properties

3. **Immediate transition:**
   - Name
   - Guard
   - Priority

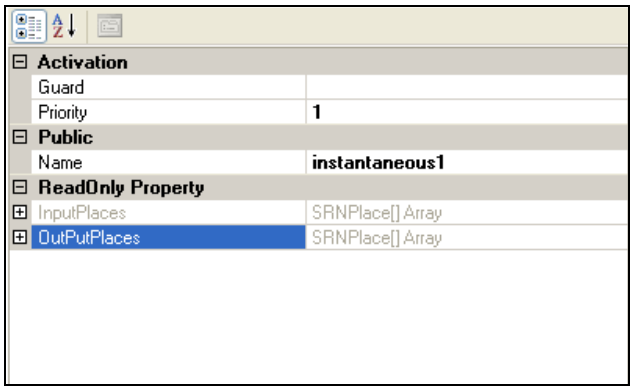


Figure 17 Immediate transition properties

4. **Arc:**
   - Multiplicity: Multiplicity of an arc can be an integer number (e.g. *2*), marking of a place (e.g. *place1.Mark*), a parameter, or an integer expression (like *2+(place1.Mark==1?0:2)*).
5. **Inhibitor Arc:**
   - If an inhibitor arc exists from a place to a transition, then the transition will not be enabled if the corresponding inhibitor place contains a token. Like Arcs, inhibitor arcs can also associate a multiplicity number.
   - Multiplicity: is like multiplicity of arcs. An inhibitor arc (between a place and an arc) with the multiplicity *m* is same as *m* replicate of a simple inhibitor arc, i.e. the transition cannot be fired if there exist more than *m* token in the corresponding place.

General Configuration

Configuration of PDETool (stored in file *config.ini* in the directory which PDETool is installed) can be changed using menu *Setting* in main console of PDETool. The *Setting* form contain following functionality:

- **Default project directory**: By default, PDETool uses directory *project* in the installation directory of the tool to store, save and load the projects (models, reward variables and etc.). It can be changed in the setting screen (Figure 16).
- **SimGine engine parameters**: To use some parameters in initialization of SimGine, you may use this field.
- **Random number generator (RNG) seed**: SimGine does not need to use a seed number for generating random numbers (automatic seed-*auto*) but you can specify a seed value (*manually*) which will be used by SimGine for RNG. PDETool does not use this value directly and it is one of the simulation engine's parameters.
- **Simulation output directory**: Result of simulation can be saved when the simulation progress is finished. In this case, output directory must be specified. You can use models directory as the output directory of simulation (*project directory\model directory\Sim*), set a permanent directory as the default destination to store simulation results, or use the *Always ask me* option.

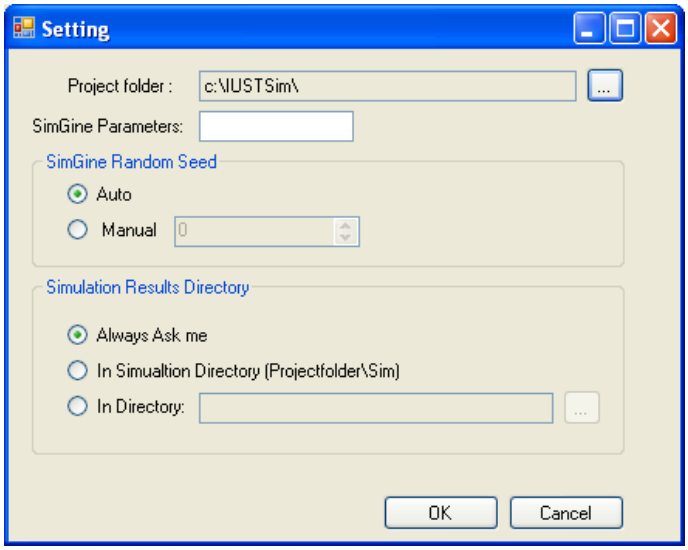


Figure 18 PDETool Setting

SDES Interface

PDETool has an interface for direct working with the SimGine. This feature is useful when the modeler wants to simulate a SimGine file (which is based on SDES description). In this situation, modeler can load, edit and simulate a SimGine file. A simple model animator is also available for this purpose.

For direct simulating a SimGine model, use SimGine Tool from menu Projects (*Projects→SimGine Tool*) in main console. This opens the *SDES Interface* presented in Figure 18.

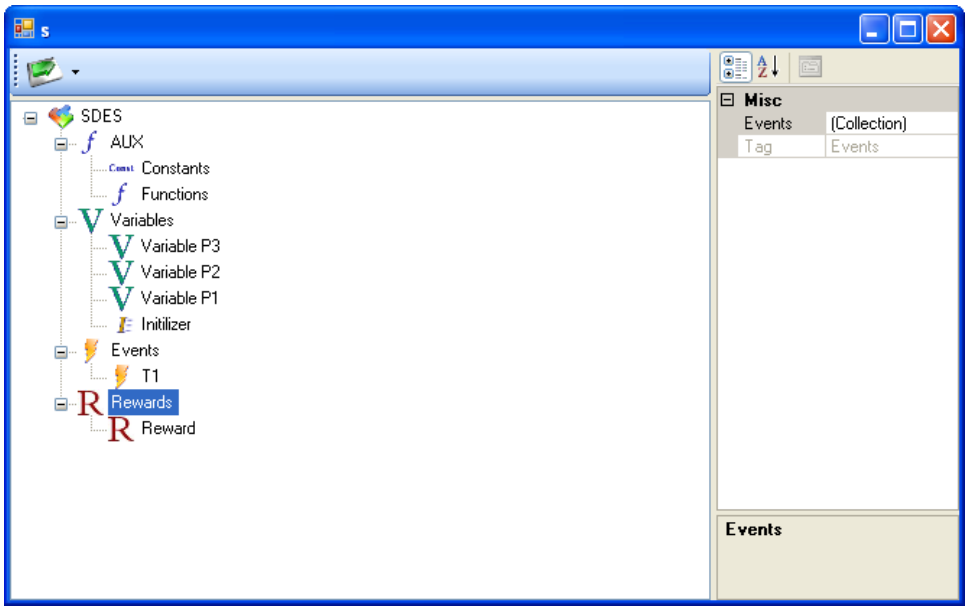


Figure 19 SimGine Interface

Specifying Reward Variables

For evaluation of models, modeler have to specify some reward variables which define functions that measure interested information about the system being modeled. One of the key features of each reward is its evaluation time. There exist two main classes of evaluation time includes *transient* and *steady state*. Transient type itself can be *instance of time*, *interval of time* and *time averaged interval*. To add a new reward variable in SAN and SRN models, use graphical icon of rewards (Figure 18) in model editor. When you create a reward variable, it is added to the list of reward variables (Figure 5-5). Like elements and variables, a reward variable has a unique identifier.

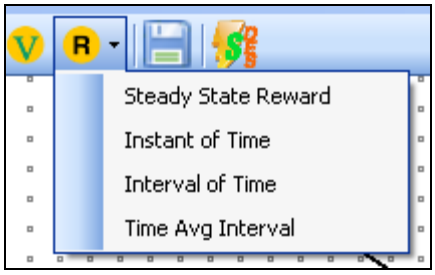


Figure 20 Add a reward variable within a particular type

PDETool and its simulation engine, SimGine, use performance reward variables which introduced in [2] and include *rate rewards* and *impulse rewards*. For each reward, it can be specified both *rate function* and *impulse function* as follows:

- A *rate function* is body of a function which assigns some quantity of reward when the model is in a particular situation and must be written in code editor (Figure 19). The situation can be checked using a conditional statement that tests the state of model (marking of places or value of global variables). Assigned quantity of reward is the (float) return value of this rate function. When model is in a specific state, if rate reward function returns value *r*, it means while model remains in that state, reward will be accumulated with rate *r*.

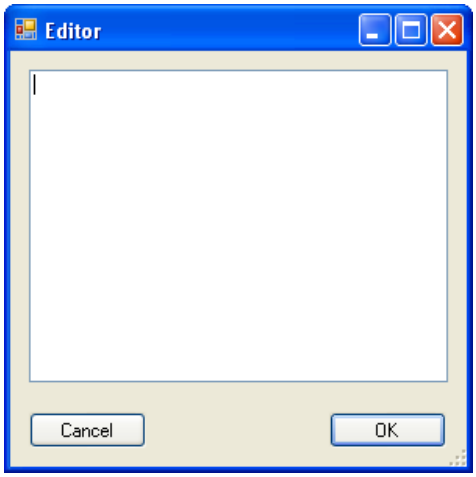


Figure 21 Rate reward editor

- An *impulse function* can be used to observe execution of some desired events and specifies amount of reward earned when state of the model changes by execution of those particular events. Name of the desired events (e.g. activities in SANs or transitions in SRNs) must be designated and body of method that its return value characterizes the amount of reward earned upon completion of the specified event must be specified in the code part of the impulse reward editor (Figure 21).

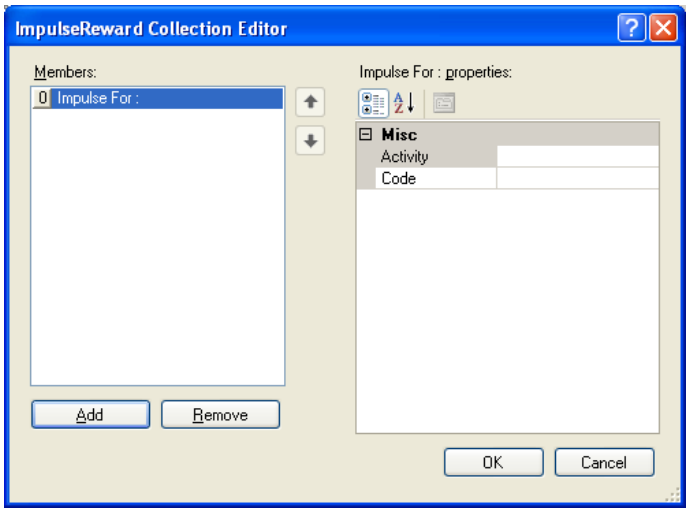


Figure 22 Impulse reward editor

In addition, for all rewards, two values must be defined named *confidence interval* and *confidence level* which determine precise of computed value of the reward and affect duration of simulation. When simulator reaches the desired confidence interval in specific *confidence level* for all reward variables, the simulation progress will be stopped. *Confidence level* can be *0.95*, *0.98*, *0.99* or *0.999*. Greater levels with smaller intervals lead to more reliable results. For timed interval rewards (timed interval and averaged timed interval), start and end time of the evaluation interval also should be defined (using properties editor as in Figure 22). For example, for instance of time rewards, the moment of evolution must be specified (Figure 23).

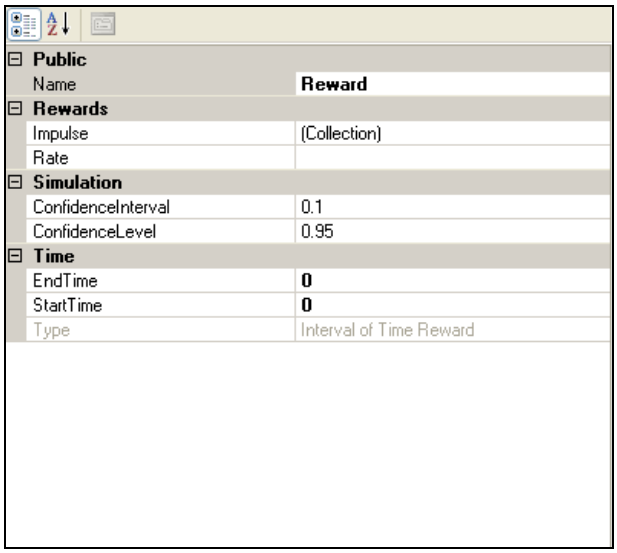


Figure 23 Properties of a reward variable with type *Interval of Time*

GSPNs performance measures

GSPNs have performance measures instead of rewards. These performance measures are translated into the rewards which can be computed during simulation progress and include following measures:

- Steady state average number of tokens in a place
- Expected number of tokens in a place at time *t*
- Steady state throughput of a transition
- Throughput of a transition at time *t*

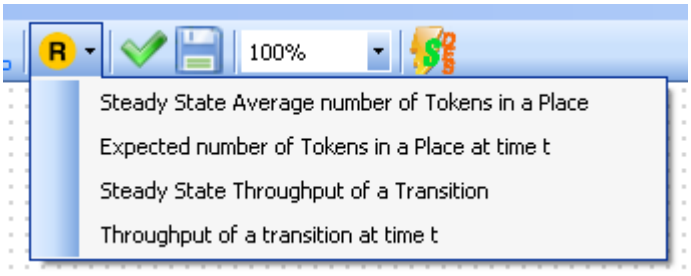

100%
Steady State Average number of Tokens in a Place
Expected number of Tokens in a Place at time t
Steady State Throughput of a Transition
Throughput of a transition at time t

Figure 24 GSPN performance measures

Model Simulation with PDETool

For simulation of a model in PDETool, modeler must first define a simulation study using *Project Editor* following these steps:

- Define a simulation study in Project Editor using menu *Simulation*.
- Open *Simulation Manager* by double clicking on the defined study.
- Use Simulation manager to setup a simulation study and simulate the model.

Simulation Manager (Figure 23) has the following parts and functionality:

- *Simulation Study Editor* (Figure 23-1):

  As mentioned before, modeler can define some global variables. A simulation study is defined by a set of values correspond to these global variables as the parameters of the simulation. A simulation study (parameters of simulation or values of defined global variables) can be saved for future use.
- *Simulation Parameters* (Figure 23-2):

  During simulation progress, graphical user interface which shows current values of rewards is updated periodically after execution of some predefined number of events which can be set by modeler in *Event per update* field. Note that low values of this field reduce the simulation speed.

  Maximum simulation time is a stop criterion, i.e. when the simulation time (model time, not computation time) exceeds this value, the simulation will be stopped.

  Minimum number of event before finish says that at least a minimum number of events (activity) must be executed (fired) before finishing the simulation (unless there is not any enabled activity or the model time exceeds the maximum simulation time).
- *Simulation type* (Figure 23-3):

  There exist two types of simulation: steady state simulation and instantaneous simulation.
- Some buttons (Figure 23-4):

  For simulating a model, you can use simulator or animator. To save the simulation studies, push *Save* button. *Token Play* and *Simulation* button are used to simulate and animate the model, correspondingly. To simulate or animate a model, you have to choose a simulation study first.

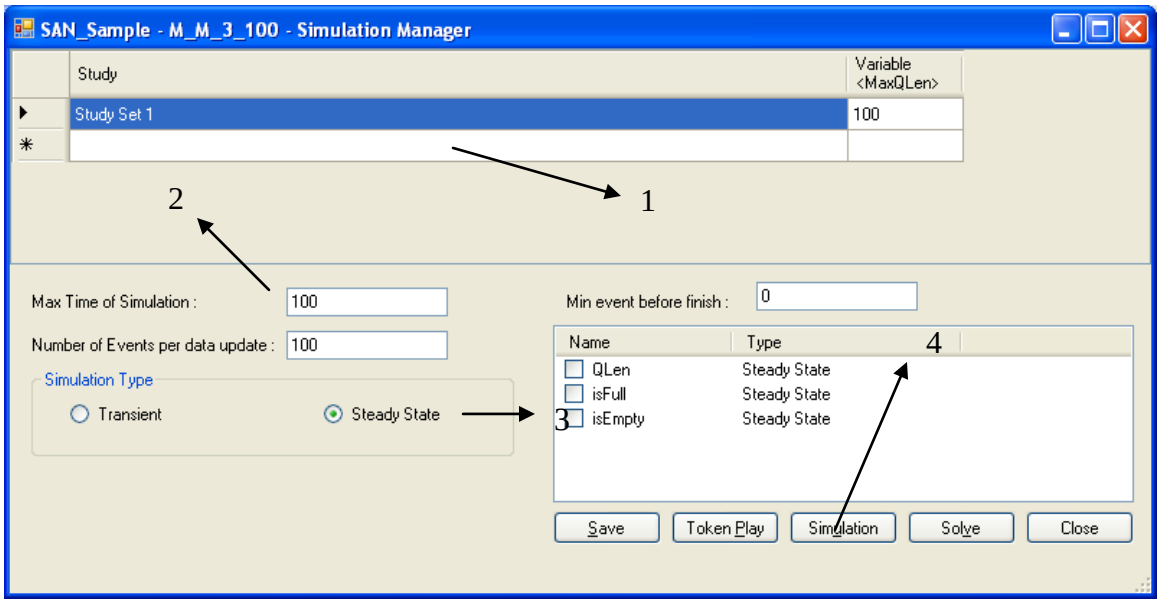


Figure 25 Simulating a model using *Simulation Manager*

Simulation using Model Simulator

PDETool provides a general graphical simulator. It can be used for any formalism which the tool can deal with.

Model Simulator, as shown in Figure 24, contains three parts: Simulation logs which log the simulation events occur during simulation progress (compilation, start, finish etc), a status bar shows simulation progress and a table that shows the current values of reward variables.

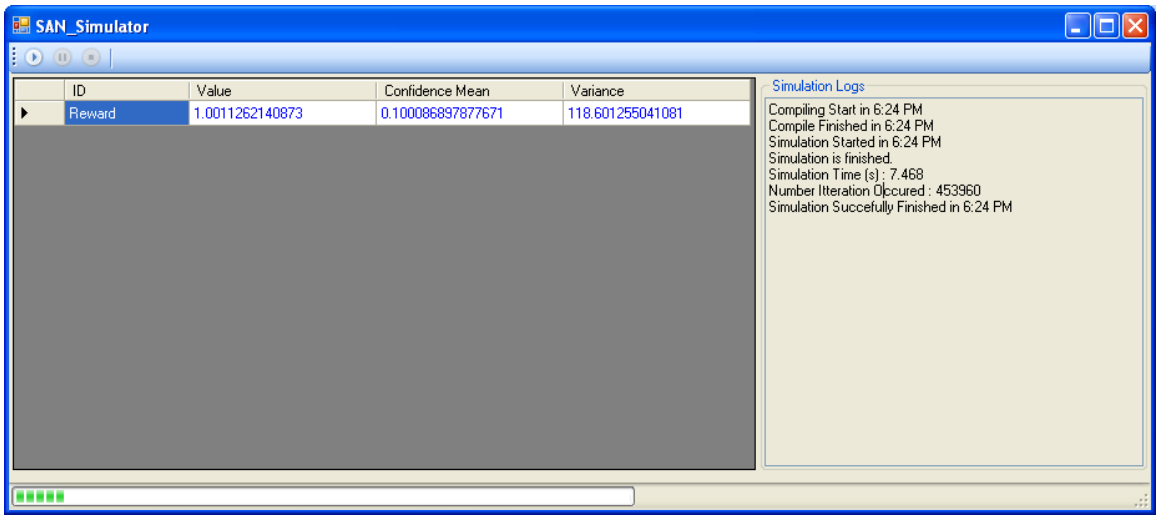


Figure 26 Model simulation using *Model Simulator*

Simulation using Model Animator

For each model type, it may be developed an optional animator that graphically animates the simulation progress. This facility is called token-game in Petri nets.
As shown in Figure 24, for example, *SAN Animator* has the following parts:

- An animator log in the right hand of the animator screen.
- A graphical animator that shows the model with the marking of each place and emphasizes the firing of activities.
- A table that shows the current values of reward variables.
- Some graphical button in top of the animator screen that control the animation progress which includes *stop* the animation, *pause* the animation, *play* (*resume*) animation, and animate event-by-event (step-by-step). You can change the speed of animation by determining interval time between events' execution (in millisecond).

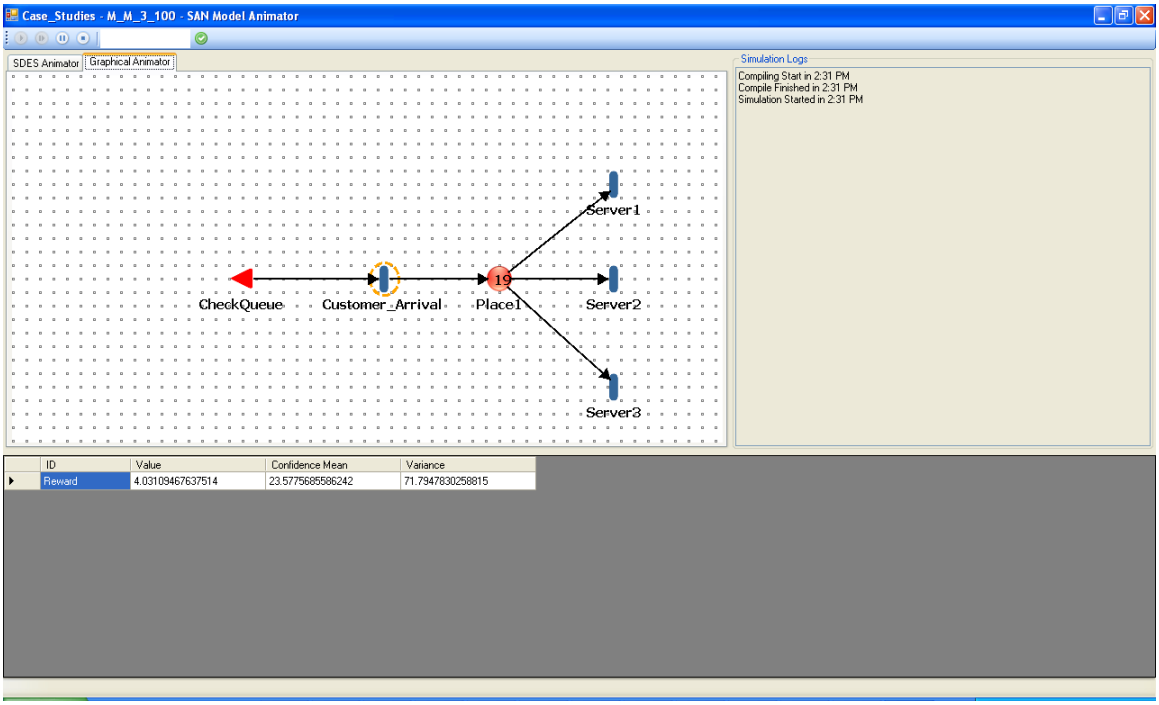


Figure 27 SAN animator in PDETool

You can also use *SDES Animator* (Figure 25). SDES animator has the following parts:

- An animator log which logs execution of each event in the model
- Table of state variables and their values (e.g. in SAN models: places and global variables)
- Table of events and their scheduling time for execution (e.g. activates in SANs).
- An event log in the left hand of screen
- A table that shows the current values of reward variables
- Some graphical button to control animation progress

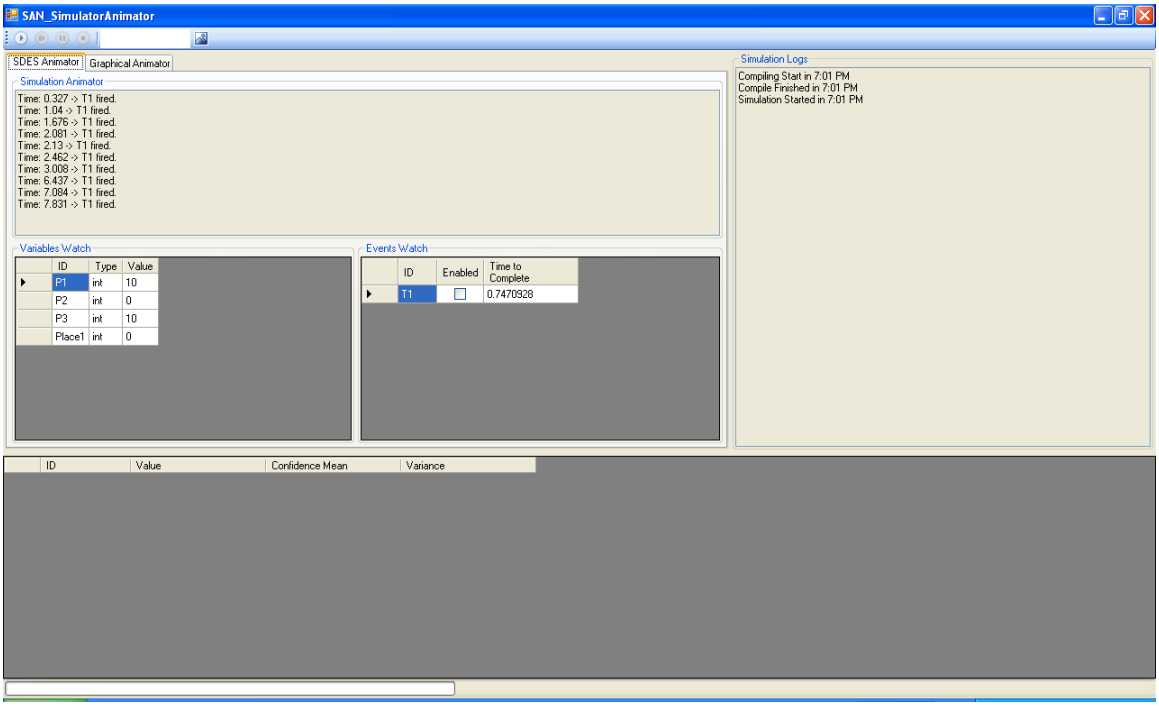


Figure 28 SDES animator in PDETool

Examples

Here, we bring some case studies which may be useful to understand modeling with PDETool. More examples can be found in the tools sample models.

Example 1: Modeling a Queue Using SANs

Consider an M/M/3/100 queueing system that is modeled in SAN. The model is depicted in Figure 27. As shown in the figure, the model has an activity for customer arrival, three activities that present service execution and a place models the number of customers in the queue. The input gate of the model controls the admission of customers. The structure of model is depicted in Figure 26. You can use the tool to export the model as an image (like Figure 28).

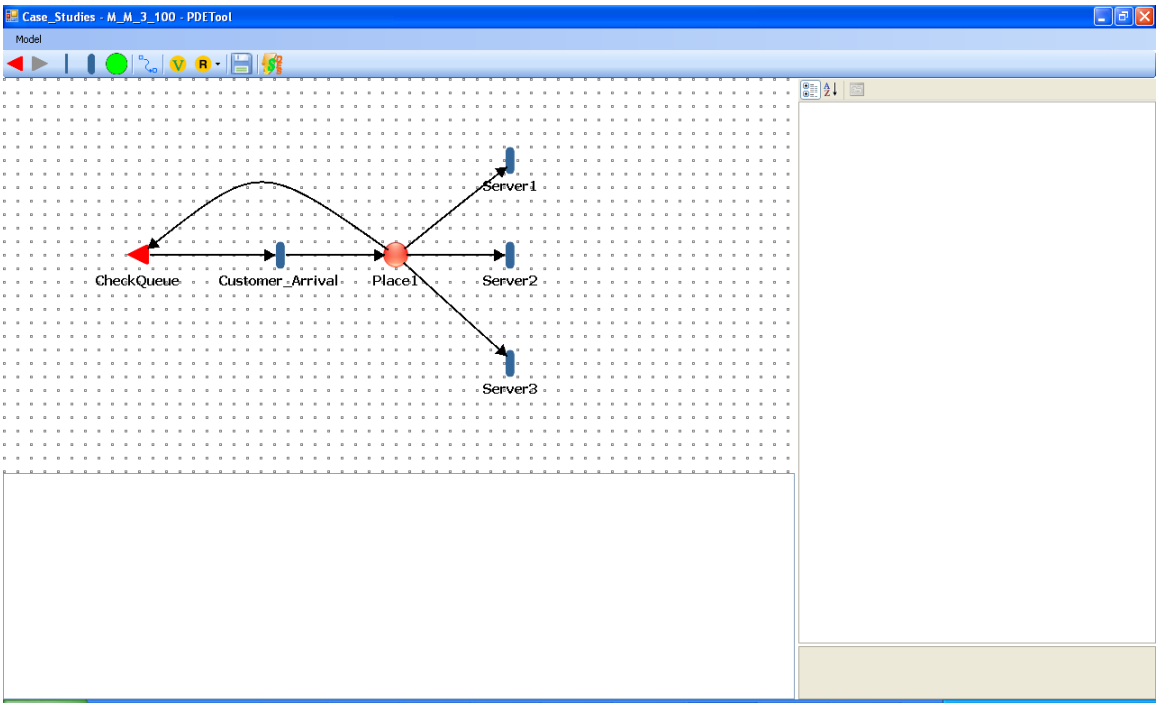


Figure 29 SAN Editor for modeling a M/M/3/100 with SAN

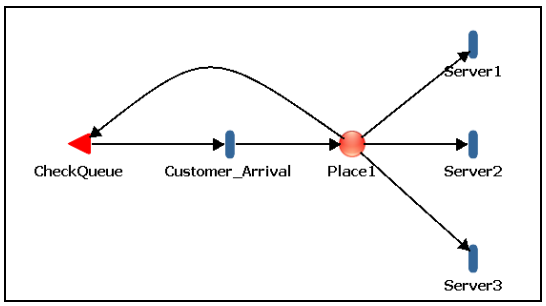


Figure 30 Exported image of model generated by SAN Editor

Table 2: Timed activities configuration of presented SAN model

Timed Activity	Distribution (rate)
Customer_Arrival	Exponential (5)
Server1	Exponential (1)
Server2	Exponential (1)
Server3	Exponential (1)

Table 2 shows the distribution and rate of all activities. The simulation results of the model with confidence level *95%* within the confidence interval *0.1* are presented in Table 3.

Table 3: Reward variable specification and simulation results

Name	Type	Value	Confidence mean	Variance
Queue length	Rate{ return Place1.Mark;}	52.045	0.28	850.94
isFull	Rate{if(Place1.Mark==100)return 1;}	0.0097	0.0009	0.0096
isEmpty	Rate{if(Place1.Mark==0)return 1;}	0.0094	0.0009	0.0093

Example 2: Modeling a packet generator system using CSANs

Consider a simple example of a packet generator system, presented in [14]. The system generates packets with random protocol type (*TCP=1*, *UDP=2* or *RTP=3*), length and priority, and inserts them into an input buffer. An error checking (e.g. a CRC check) is done on the generated packets. If an error is detected, the packet will be discarded; otherwise, it will be routed to output buffers. Packets are routed probabilistically to two output buffers with probability *0.599999* and *0.4*.

The probability of detecting an error is *0.000001*. The initial capacity of the system is 6 and it will stop whenever *6* packets are in error and have been discarded. The graphical representation of the model is shown in Figure 30. Reward variables, color definitions and global variables are also be defined in model editor. For example, in this case study, we define a color named *TPacket* as follows:

```
TPacket={
        byte Protocol;
        int Len;
        byte Prioriy;
}
```

The model is composed of a simple place (*Capacity*), three coloured places (*InBuf*, *OutBuf1* and *OutBuf2*), five input gates (*IG1*, *IG2*, *IG3*, *IG4* and *IG5*), three output gates (*GenGate*, *OG1* and *OG2*), three timed activities (*GenPacket*, *Send1* and *Send2*), and three instantaneous activities (*Route1*, *Route2* and *ErrChk*). The selection policy for *InBuf* is FIFO and for *OutBuf1* and *OutBuf2* is Priority. The Priority function of these two coloured places that determines the priority of sending packets from the each output buffer and other parameters of the model are shown in Table 4 which depicts parameter table for the definition of priority functions of coloured places and enabling predicates and functions of input/output gates of the model.

The CSAN model has also a global variable *tempPacket* within type *TPacket*. In the initial marking of the model, there are three tokens inside Capacity and two coloured tokens inside *InBuf*. There is also one token inside *OutBuf1* and no token inside *OutBuf2*.

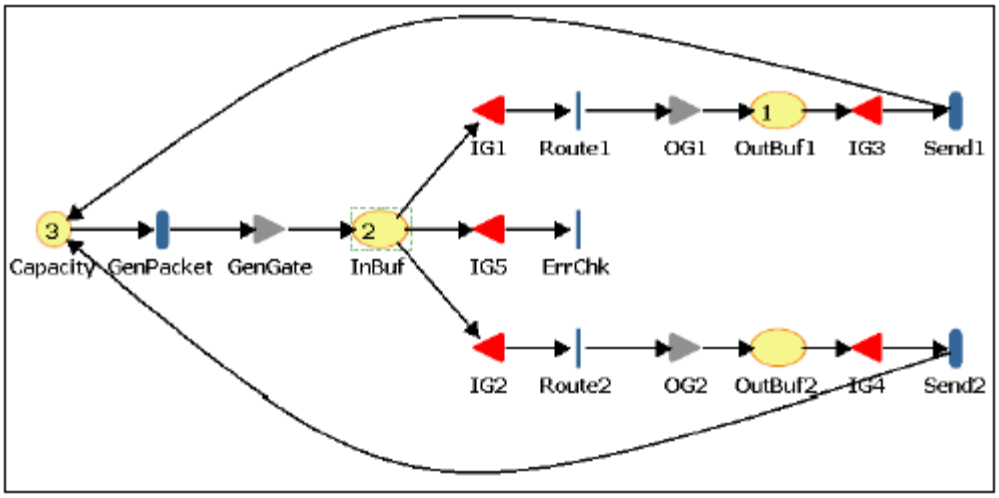


Figure 31 CSAN model of the presented packet generator

To evaluate the constructed model, modeler must define some reward variables. After definition of model and related reward structures, the model can be evaluated by Model Simulator. For example, if *Reward1* and *Reward2* are steady state rate rewards which denote the average number of tokens in *OutBuf1* and *OutBuf2* respectively, the simulation results obtained from Model Simulator depicted in Table 5.

Table 3: Parameters of the presented CSAN model

Element	Parameter	Value
OutBuf1	PriorityFunc	return TPacket.Priority;
OutBuf2	PriorityFunc	return TPacket.Priority;

GenGate	Function	tempPacket = new TPacket();
		tempPacket.Protocol =
		(byte)(Distribution.Random(3)+1);
		tempPacket.Len = Distribution.Random(100);
		tempPacket.Priority =
		(byte)Distribution.Random(5);
		InBuf.Add(tempPacket);

IG1	Enabling Predicate	InBuf.Mark > 0
	Function	tmpPacket = InBuf.Remove();
OG1	Function	OutBuf1.Add(tmpPacket);
IG2	Enabling Predicate	InBuf.Mark > 0
	Function	tmpPacket = InBuf.Remove();
OG2	Function	OutBuf2.Add(tmpPacket);
IG3	Enabling Predicate	OutBuf1.Mark > 0
	Function	tmpPacket = OutBuf1.Remove();
IG4	Enabling Predicate	OutBuf2.Mark > 0
	Function	tmpPacket = OutBuf2.Remove();
IG5	Enabling Predicate	InBuf.Mark > 0
	Function	tmpPacket = InBuf.Remove();

Table 4: Reward variable specification and simulation results

Reward	Value	Confidence	Variance
Reward1	1.20341797	0.018929343	1.980087407
Reward2	0.60774698	0.012793362	0.904446091

Example 3: SRN model of a multi processor system

Consider a simple multiprocessor system consisting of two dissimilar processors P1 and P2 as in [15] which can be failed and repaired. The system is functioning as long as one of the two processors is functioning and failures of the two processors to be independent.
While both processors work, the time to occurrence of a failure in the two processors P1 and P2 is assumed to be a random variable with the corresponding distributions being exponential with rates λ_1 and λ_2, respectively. When only one processor is functioning, the rate of failure could be correspondingly altered to reflect the fact that a single processor shares the load of both the processors. When only P1 is functioning, we assume its failure rate is λ'_1 and when only P2 is functioning, its failure rate is λ'_2. The both processors can also fail simultaneously in exponential time λ_c.
Assume that the system has imperfect coverage of the failure of the processors. Whenever a processor suffers a failure, with some probability *c*, called the coverage probability, the failure is properly detected. With probability *1-c*, the processor suffers an uncovered failure, wherein the failure goes undetected. We assume that this undetected failure results in the other normal processor also failing, causing the system failure.

We could consider repair of the processors where the time to repair the processors is also exponentially distributed with rates δ_1 and δ_2, respectively. We also assume that when both the processors are waiting for repair, P1 has priority for repair over P2.

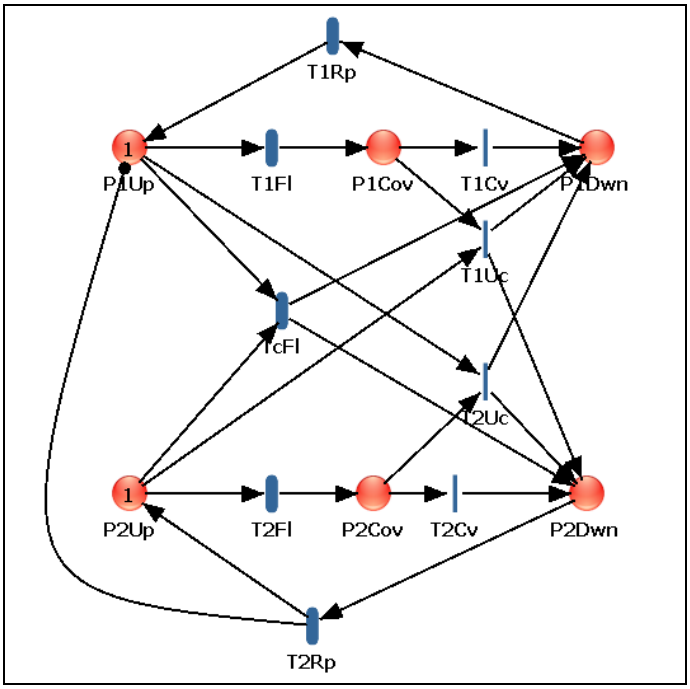


Figure 32 SRN model of the multi processor system

Table 5: Availability of the multiprocessor system

C	**0.1**	**0.8**	**0.9**
Availability	0.5629779	0.5629779	0.56297792

Appendix A: Known bugs and limitation

Here is the list of known bugs:

- Exporting model as an image has bug (when the model is bigger than the screen).
- In graphical editor, multiple elements cannot be selected.

We appreciate your feedback on this tool and bugs report by sending an email to: pdel@iust.ac.ir. Please look at the home page of the tool for more information on how to get in contact with the developers.

Reference:

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